Horn Current Studies

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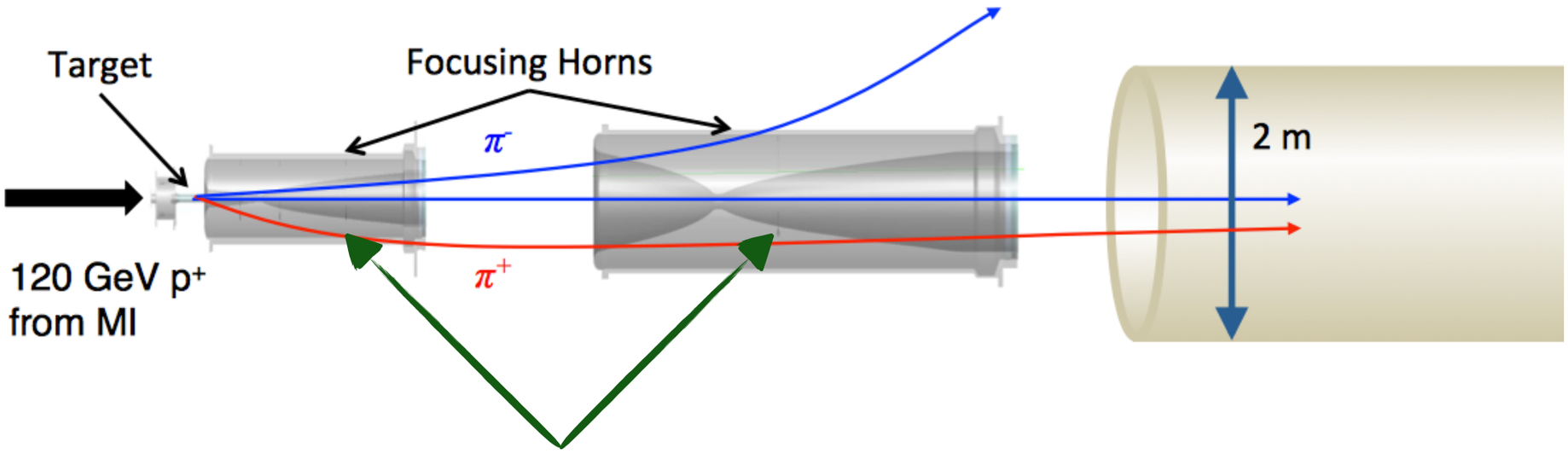
NuMI-X Meeting

September 11, 2015

Fermilab

Horn Current Studies

This studies show how the number on ν_μ events changes at the NOvA near detector if the horn current is decreased from the nominal value of 200 kA.



The horn current has been changed to
i = 190, 180, 170, 160 and 140 kA.

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Special Runs

Current [kA]	Day	Start Time	End Time	ND run	Value read [kA]	Notes
160	06/08/2015	9:41	17:51	10974	158/159	
140	06/09/2015	14:10	22:00	10978	138/139	From 17:16 to 18:32 beam power was 260kW (instead of 240) and intensity was 24e12 (instead of 32e12)
190	06/10/2015	14:36	22:00	10982	188/189	No beam from 17:56 to 19:10.
180	06/11/2015	15:07	18:28	10987	178/179	From 14:00 to 15:00 ND didn't work.
180	06/11/2015	18:39	18:54	10988	178/179	A small run again at 180 since was impossible to contact Minos
170	06/11/2015	18:56	22:03	10989	168/169	
180	06/12/2015	13:59	17:55	10991	178/179	
170	06/12/2015	17:57	22:02	10992	169	

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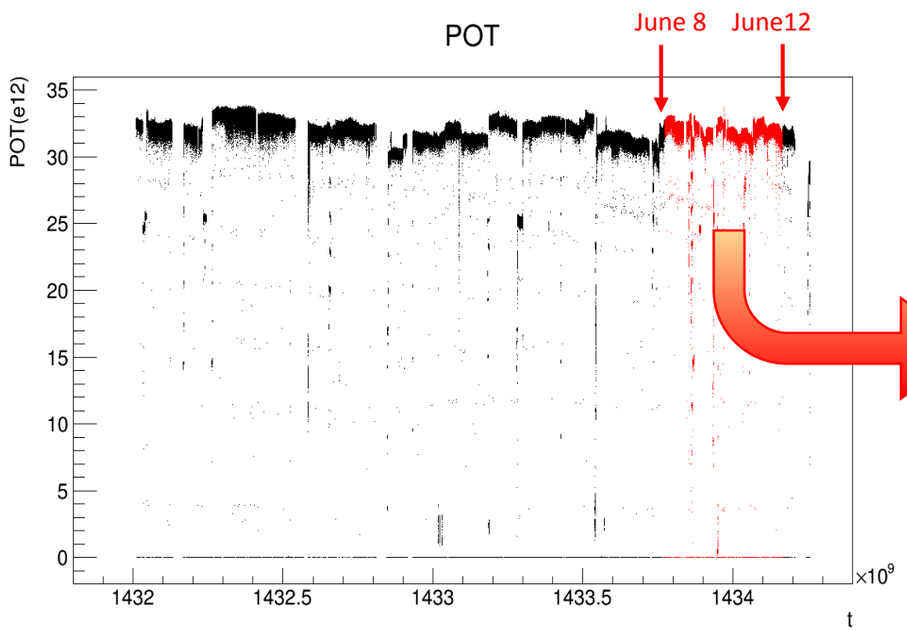
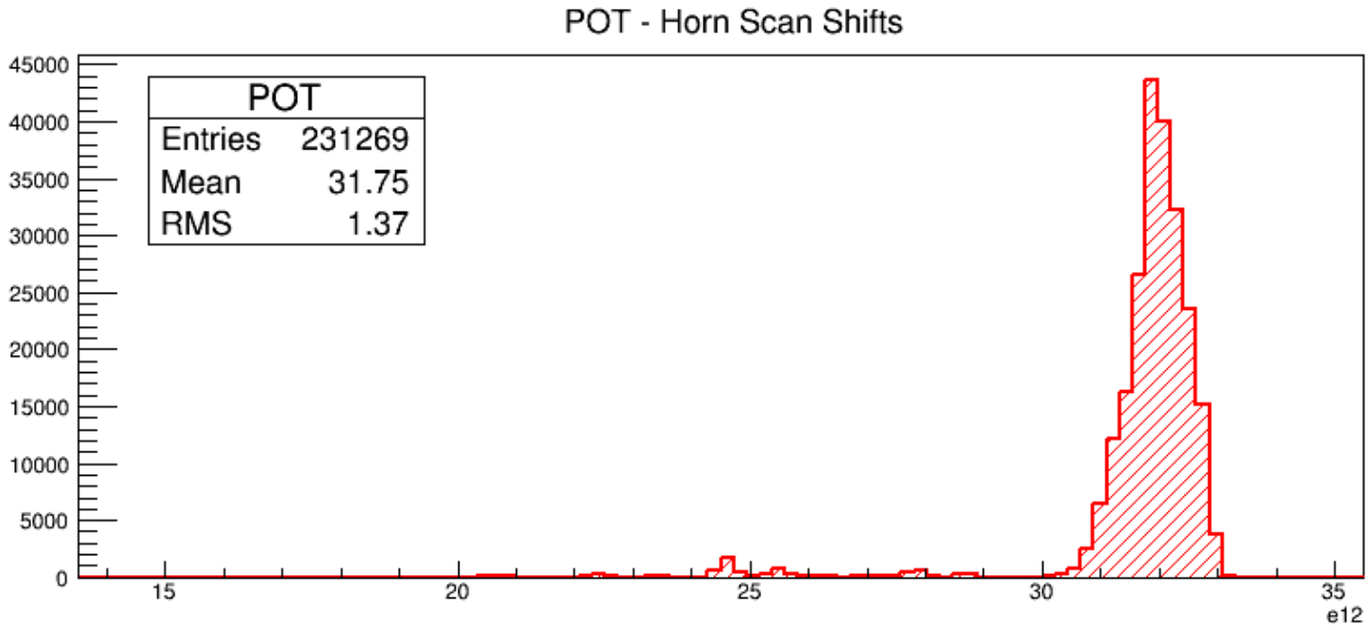
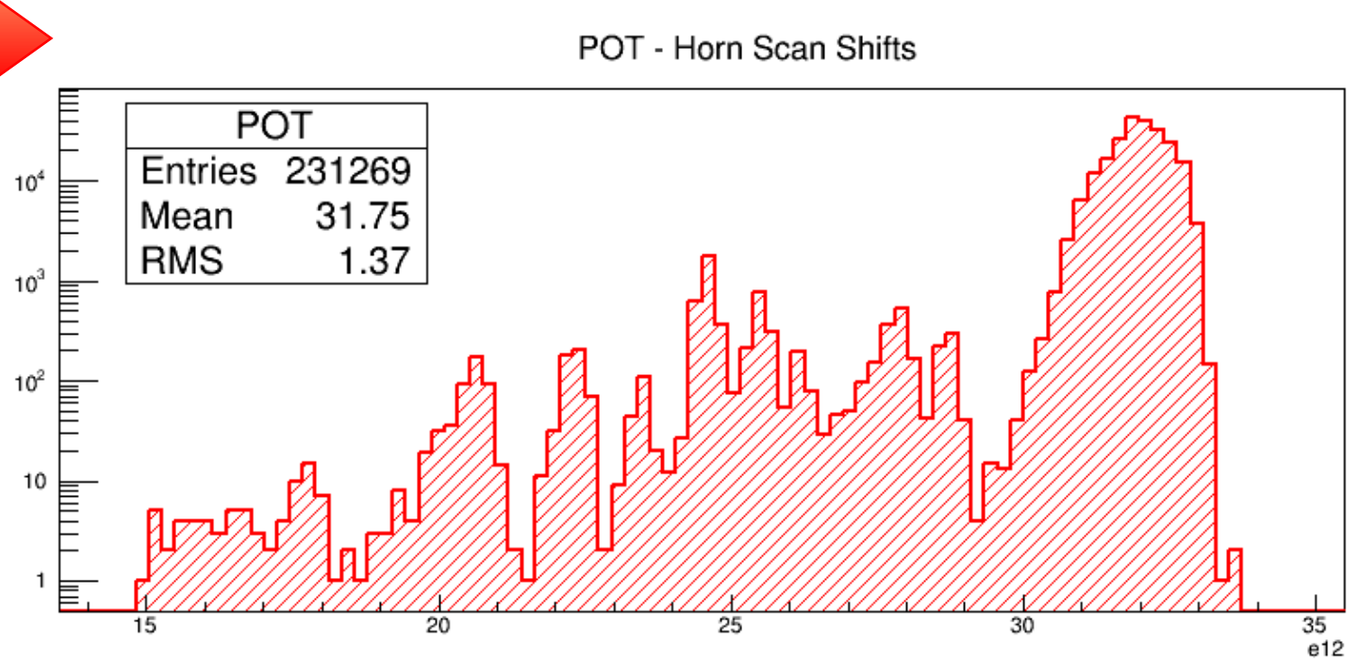
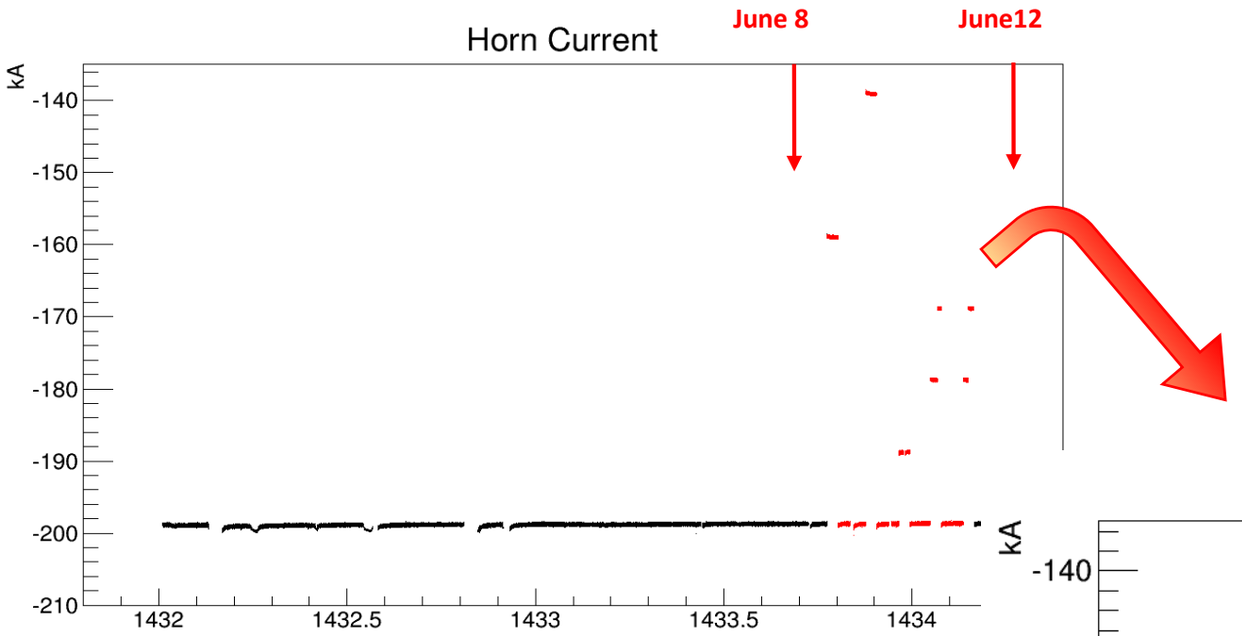
Accumulated POTs

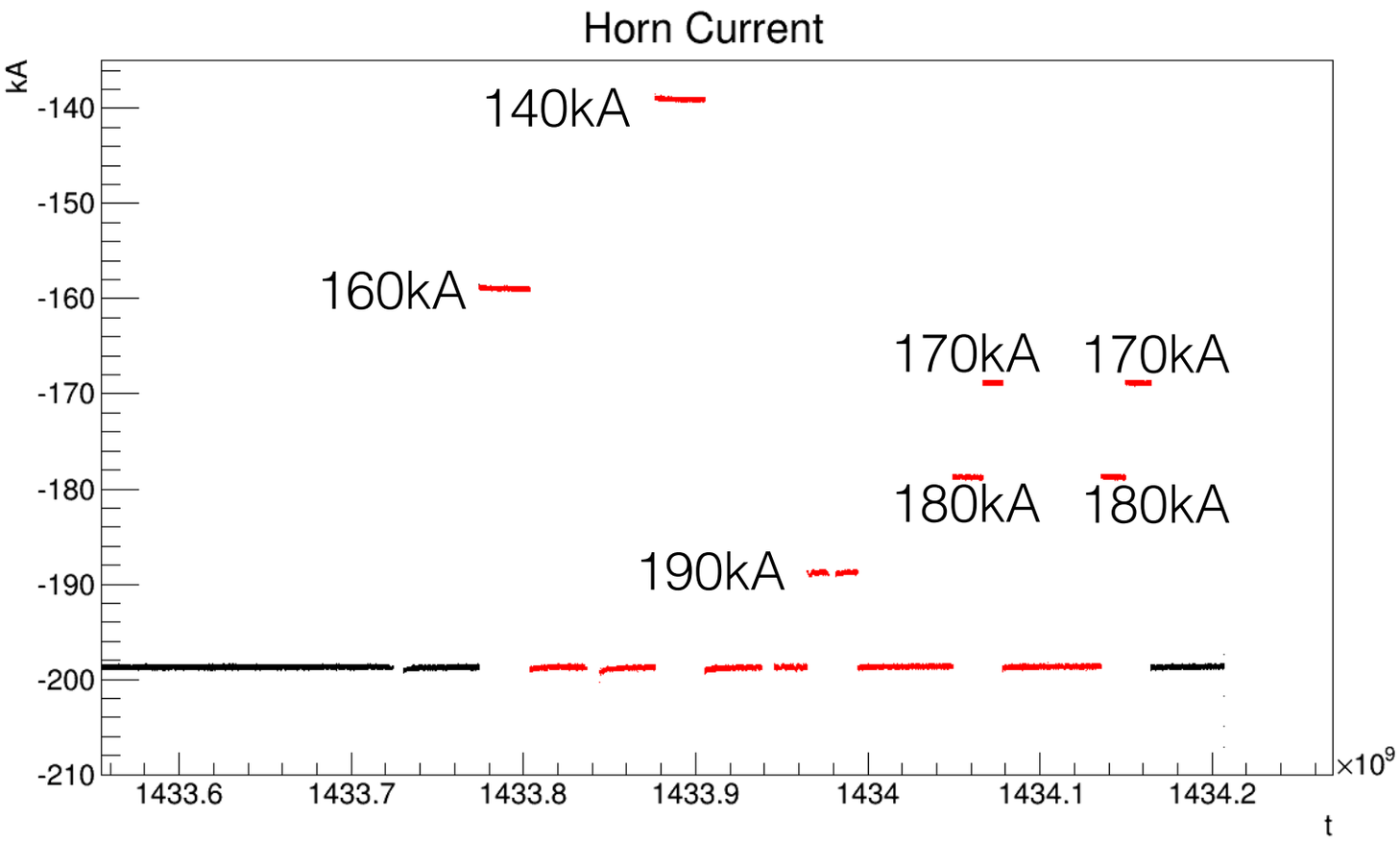






Horn Current

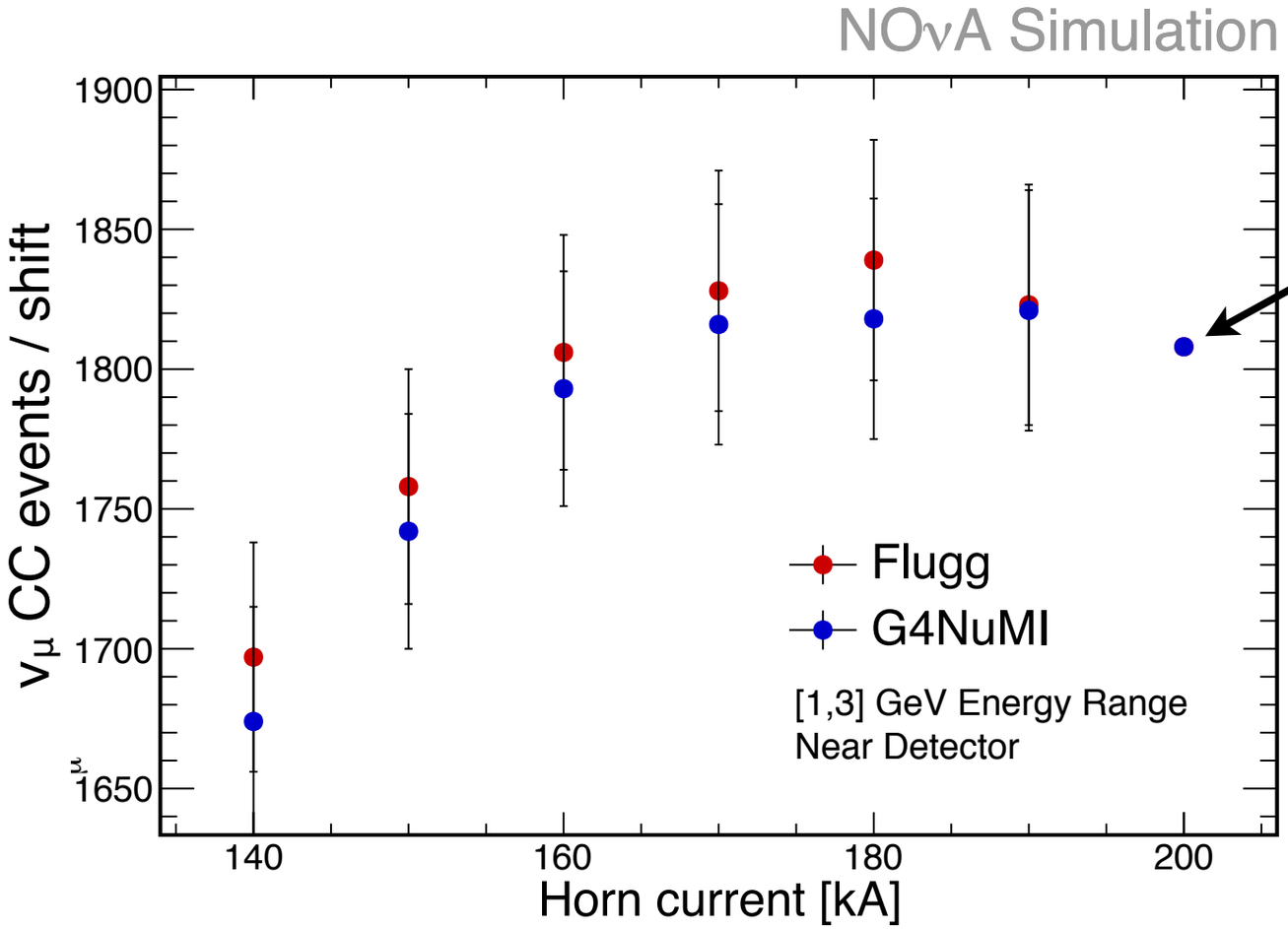




Horn Current Studies

See NOvA doc-db 13360.

The idea of performing these Special Runs was guided by the Monte Carlo simulations (FLUGG and G4NuMI). They predict that the neutrino yield for NOvA is almost constant if the horn current is turned down to 160 kA (the nominal value is 200 kA).



The number of events has been pinned at 200 kA using the data*, and then scaled, using the simulation, to get the expected number of events at lower horn current.

Events a *i* kA =
(FR predicted events per kton at *i* kA) *
(ND selected events at 200 kA) /
(FR predicted events per kton at 200 kA)

(FR = FluxReader)

*: See Louise Suter (NOvA doc-db13212) and Jaroslav Zalesak (NOvA doc-db 9526).

Motivations we had when we proposed the Special Runs

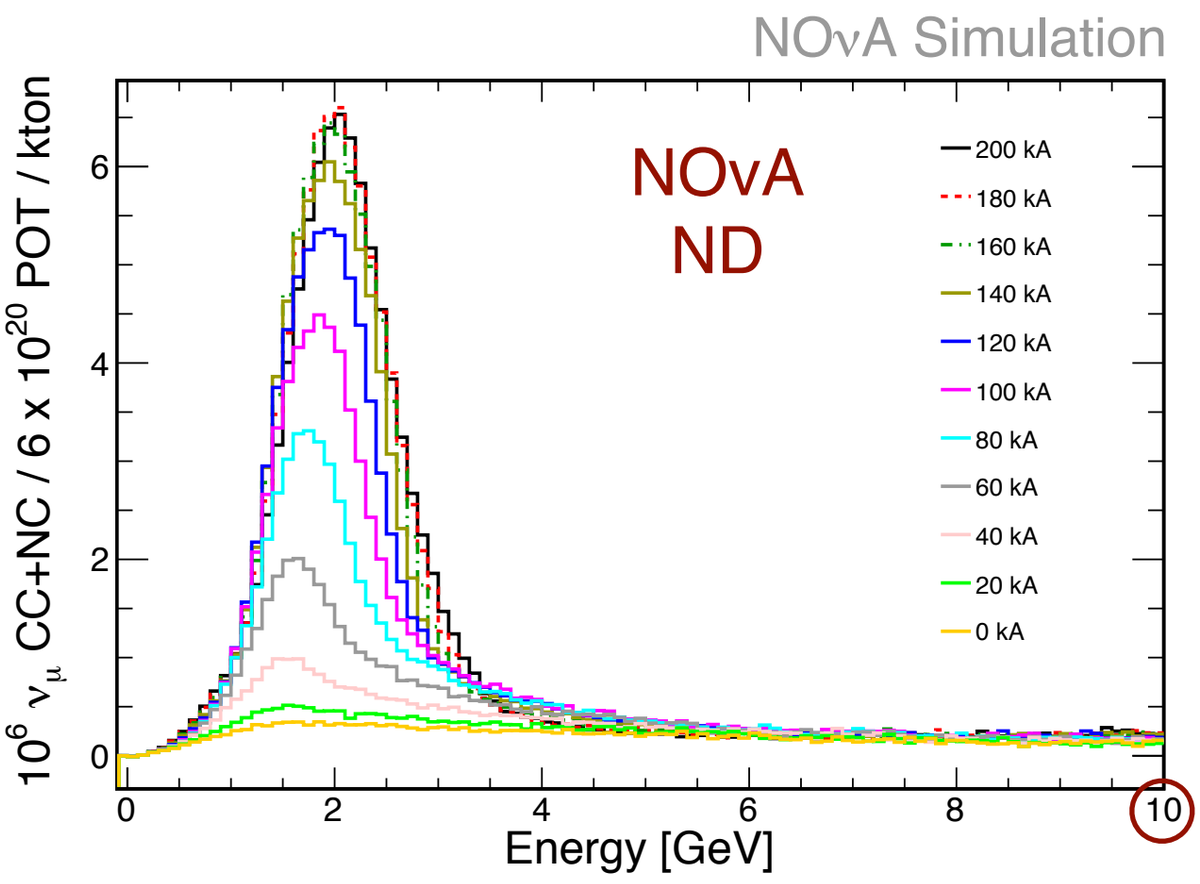
See NOvA doc-db 13451.

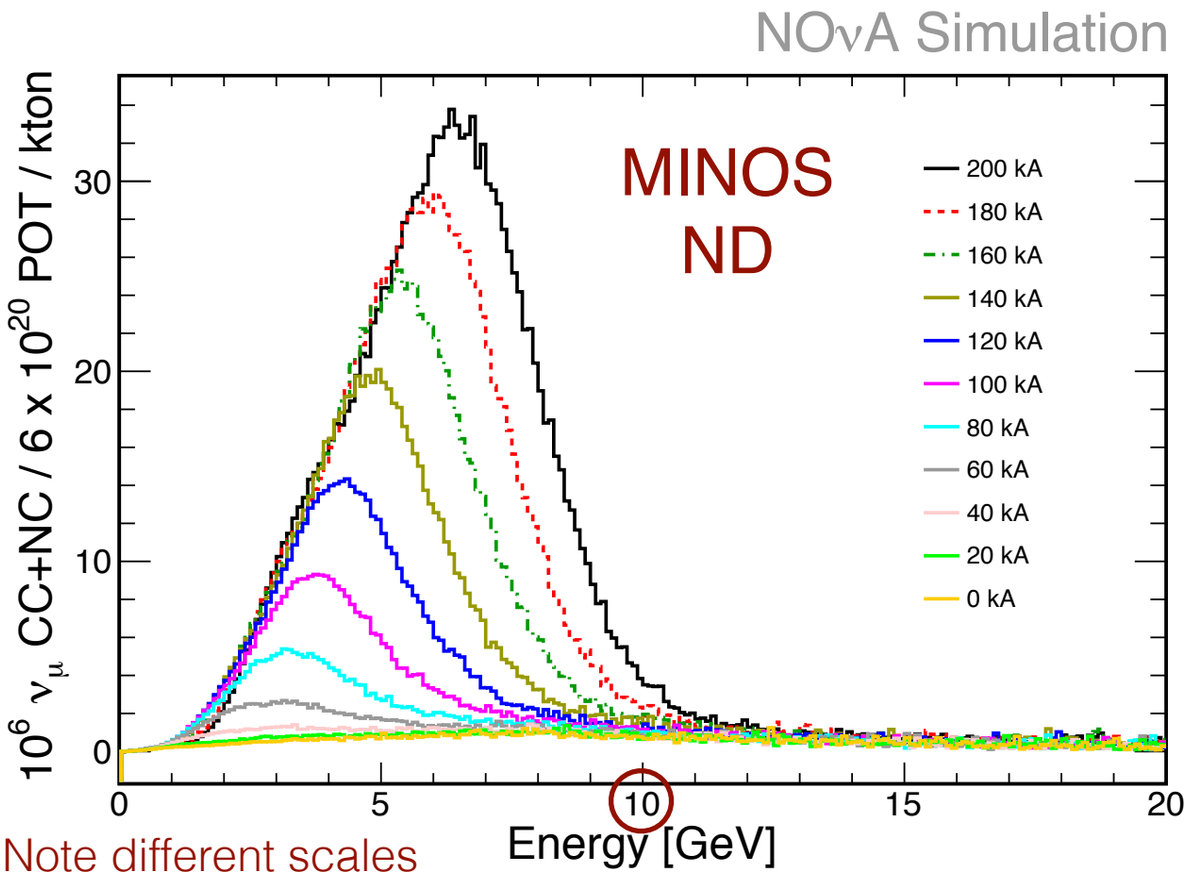
1. It gives us a data/MC comparison;
2. When the horn current is turned down, there is a big decrease of number of events on-axis, while it seems to be constant for an off-axis detector (see next slide). We can verify this behavior;
3. Horn 1 will be near the edge of its design for heating of the inner conductor at 700 kW;
4. If the neutrino yield was almost constant, we could turn down the horn currents in future running, this should improve the horn lifetime;
5. 160 kA puts much less stress on the stripline, the Accelerator Division could study that as a potential solution;

On and Off-Axis

See NOvA doc-db 13360.

The following plots show how the neutrino energy spectrum changes if the horn current is decreased. Both for an on and off-axis detector.





Note different scales

The MC predicts a very different behavior on-axis w.r.t. off-axis:

- big decrease of events for Minos.
- the peak position shifts towards low energy as the currents are turned down.

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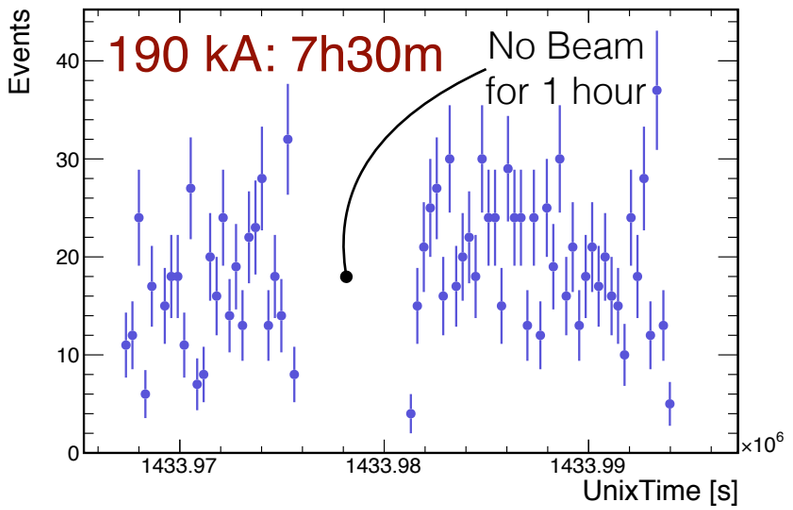
Data Tacking

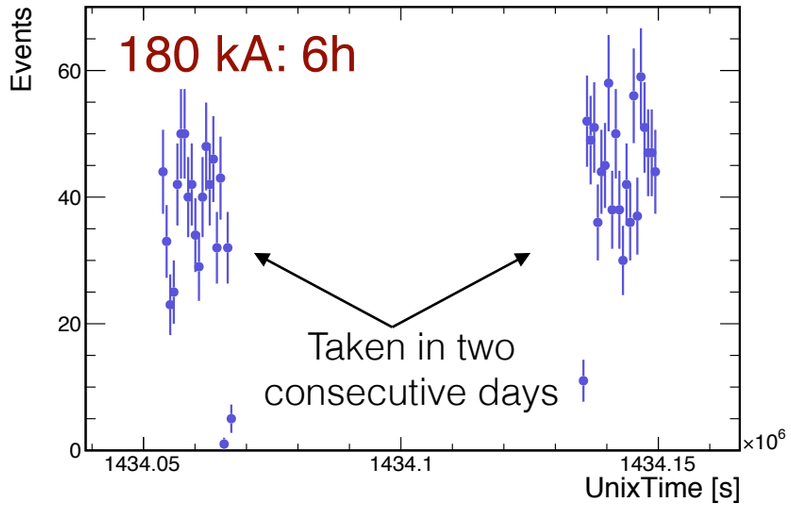
See NOvA doc-db 13523.

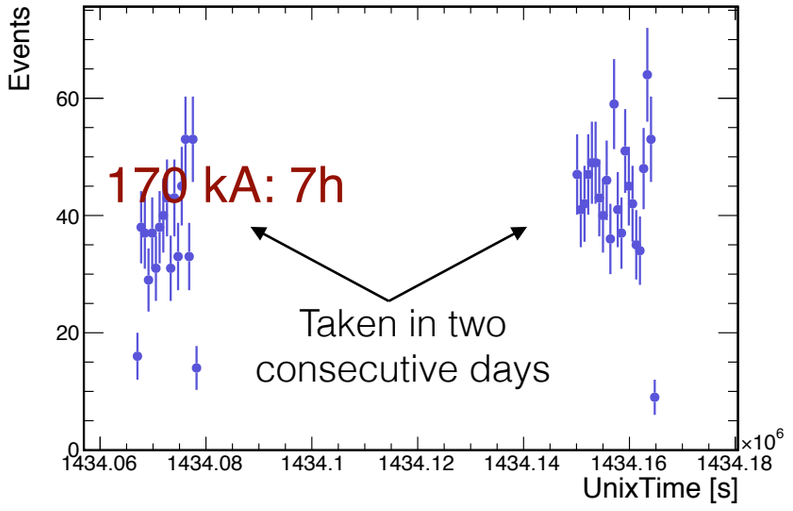
Data have been taken in one week starting from 06/08/15 to 06/12/15.

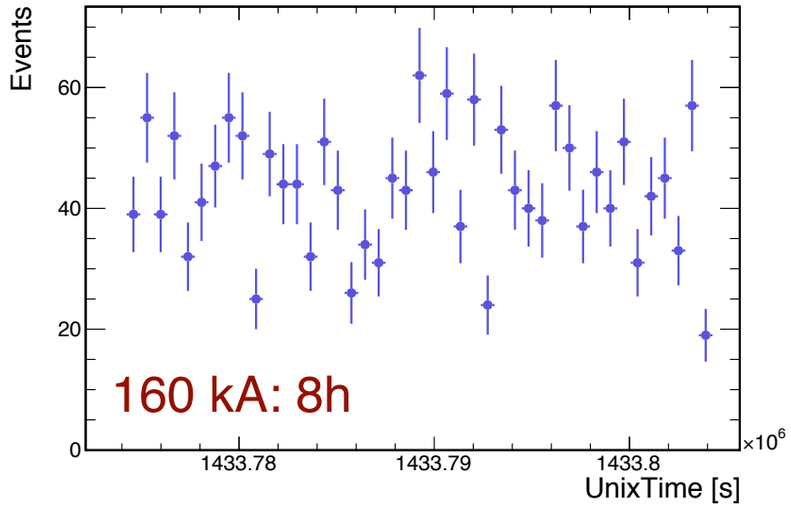
HC [kA]	Accumulated POT
200	1.66E+20
190	4.08E+17
180	5.45E+17
170	5.40E+17
160	6.29E+17
140	5.52E+17

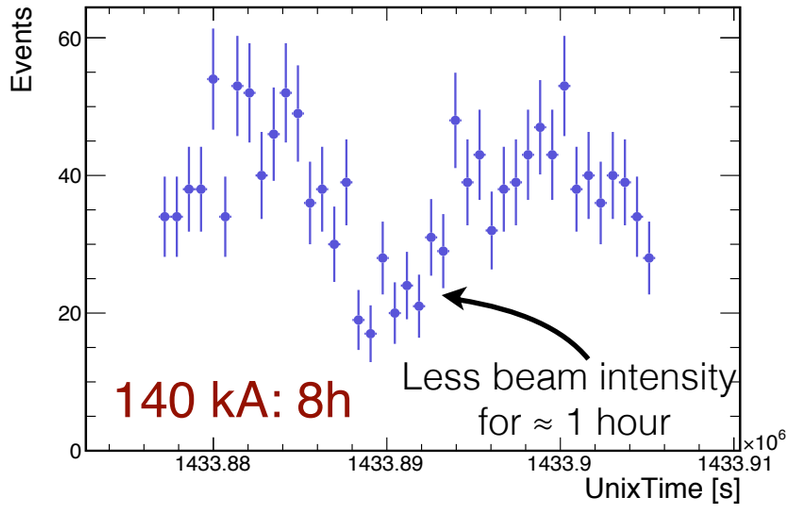
Events as a function of time (every ≈ 10 minutes).











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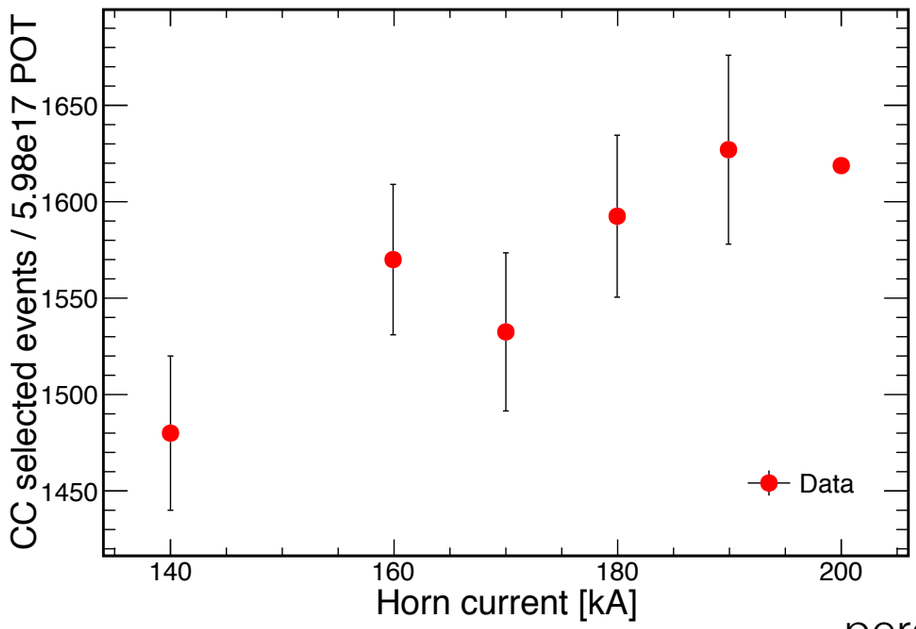
Events VS Horn Current



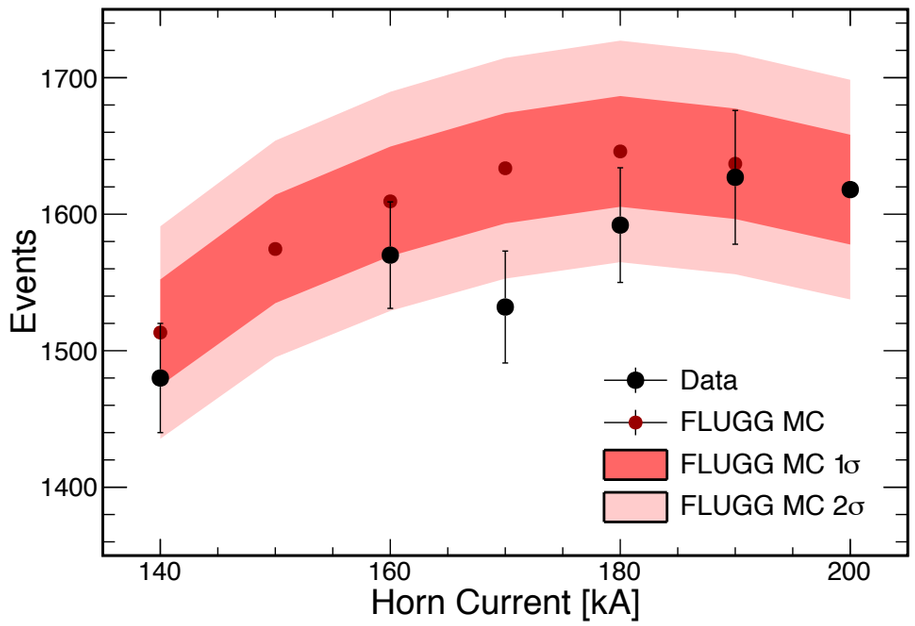
(Yield @ 160) - (Yield @ 200) = percent
- (2.8 ± 2.4) %

Neither MCs describe perfectly the change in neutrino yield.

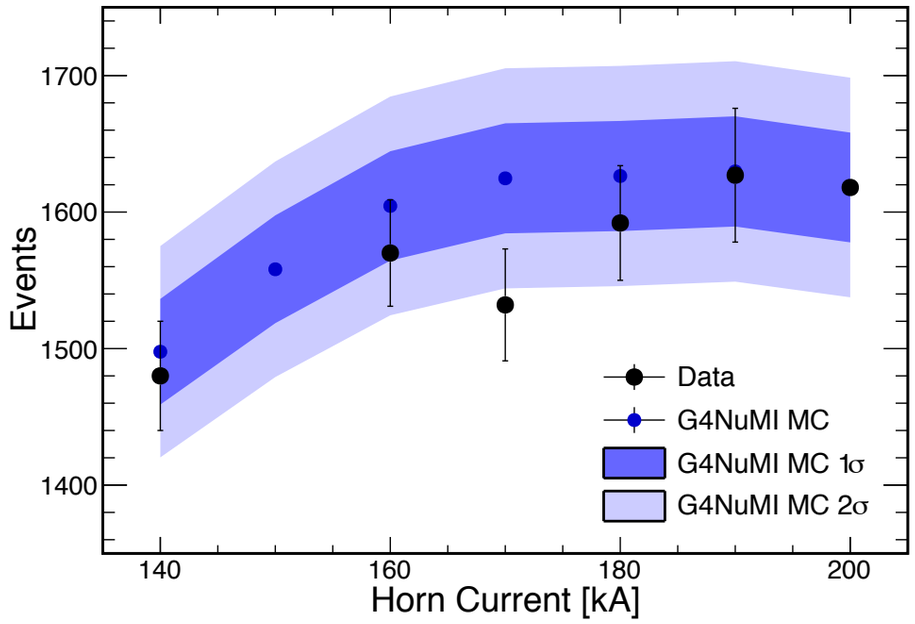
FluxReader:

- doesn't include the whole detector simulation;
- simulates flux only at the center of the upstream face of the detector (in a 1 meter radius circle);

NOνA Preliminary



FLUGG



G4NuMI

The two bands represented are <u>not</u> the MC statistical or systematic errors, but are 1 sigma and 2 sigma deviations from the FR simulated point, i.e. $\pm sqrt(n)$ and $\pm 2sqrt(n)$ where n is the FR simulated point.

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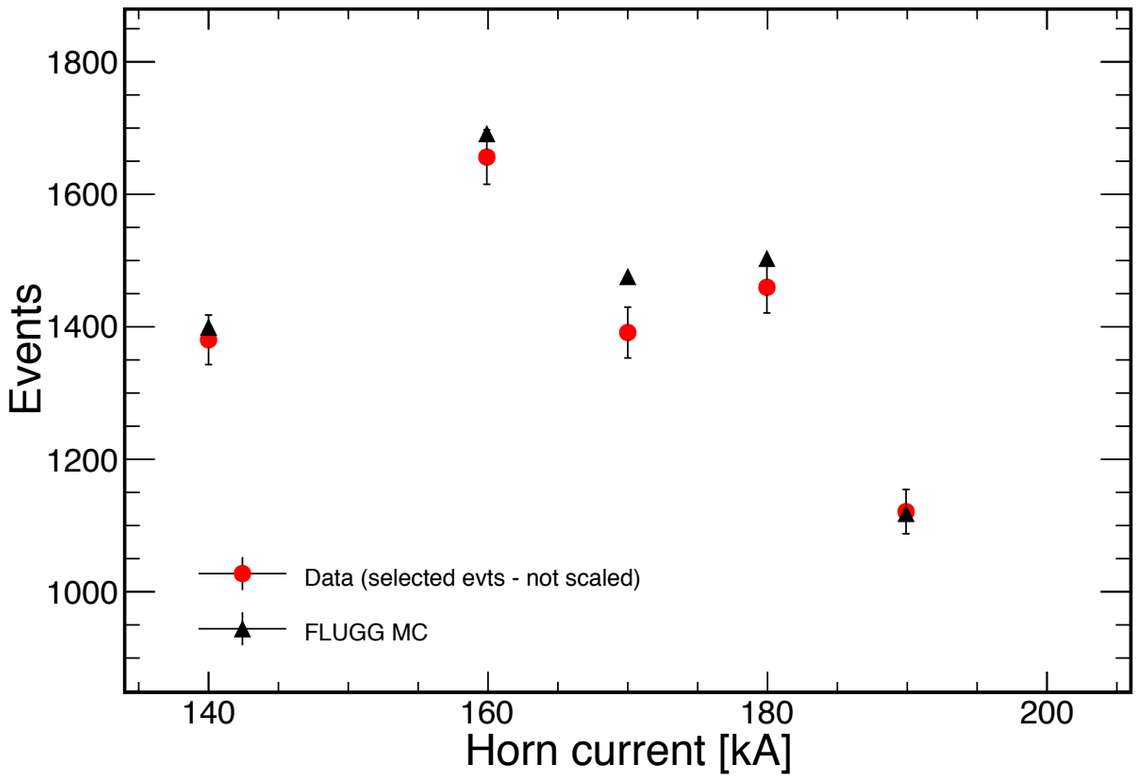
Fit data-MC — Likelihood

First, a likelihood test was performed. The plots on this slide show the number events counted for each value of the horn current in red. These values are not scaled by any POT number, so they correspond to different accumulated POTs. The black points are the FluxReader expected events scaled by the POT value of the data.
Given that, a likelihood function can be constructed as a product of probabilities to get our events, given the FR expected values:

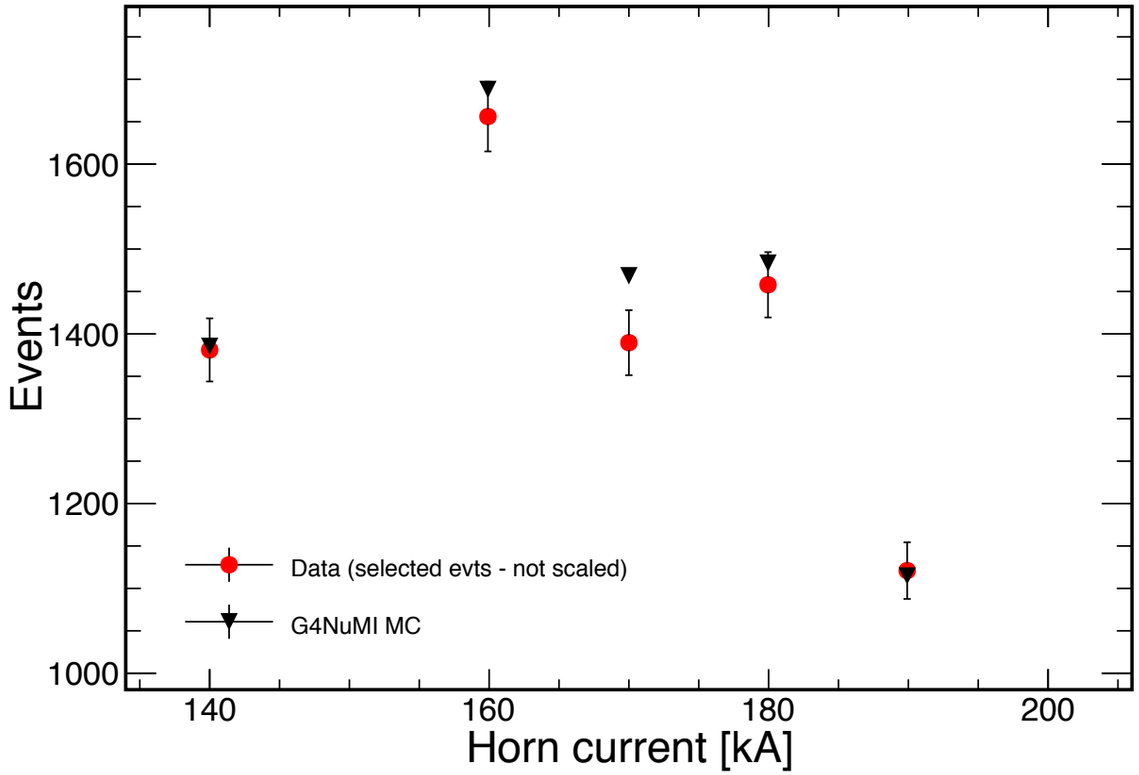
$$L(n|y) = \prod_{i=1}^{M} \frac{e^{-y_i} y_i^{n_i}}{n_i!}$$

M: number of bins
$\mathbf{y_i}$: FR evts in bin i
$\mathbf{n_i}$: data evts in bin i

FLUGG



G4NuMI



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Fit data-MC — Likelihood

Then a chi-squared test can be performed in the following way:

$$\chi^2 = -2 \ln \frac{L(n|y)}{L(n|\nu)}$$

And for the poissonian case:

$$\chi^2 = -2 \sum_{i=1}^{M} \left(n_i \ln \frac{y_i}{n_i} \right) + 2(N_0 - N)$$

The results are (degree of freedom = 5):

FLUGG

$$\chi^2_F = 7.5$$

$$P(\chi^2 > \chi^2_F) = 18.6\%$$

G4NuMI

$$\chi^2_G = 5.4$$

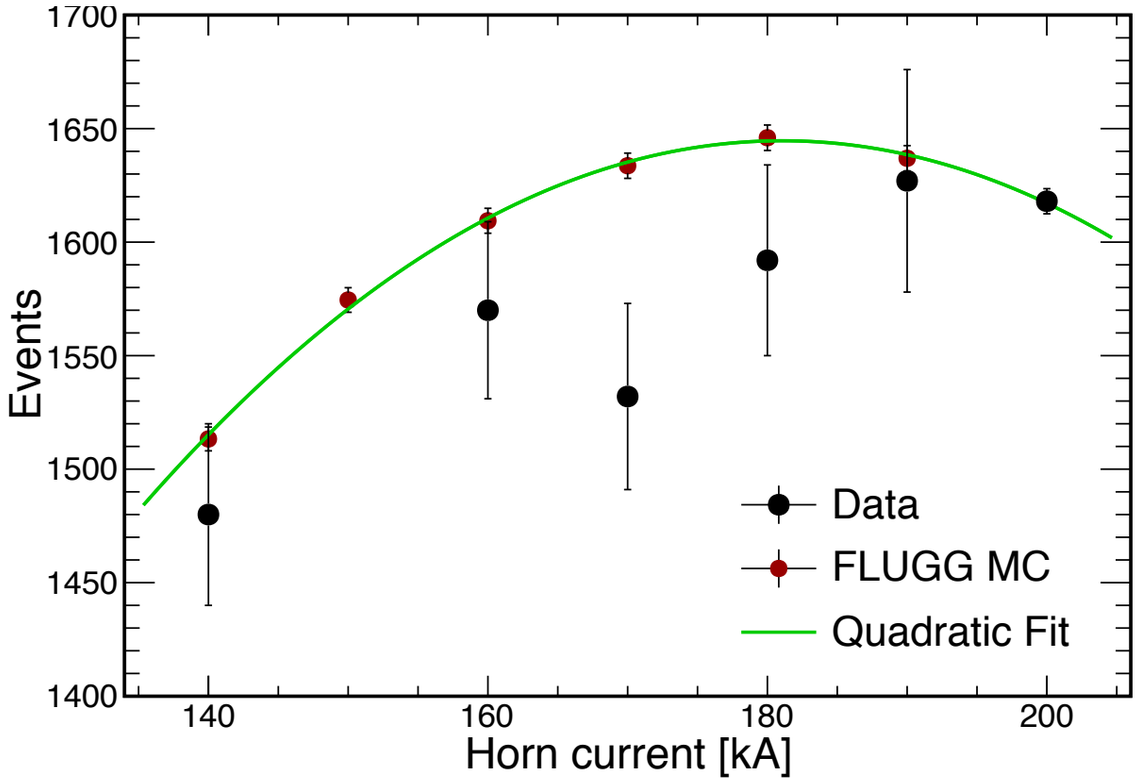
$$P(\chi^2 > \chi^2_G) = 36.9\%$$

Fit data-MC — Function

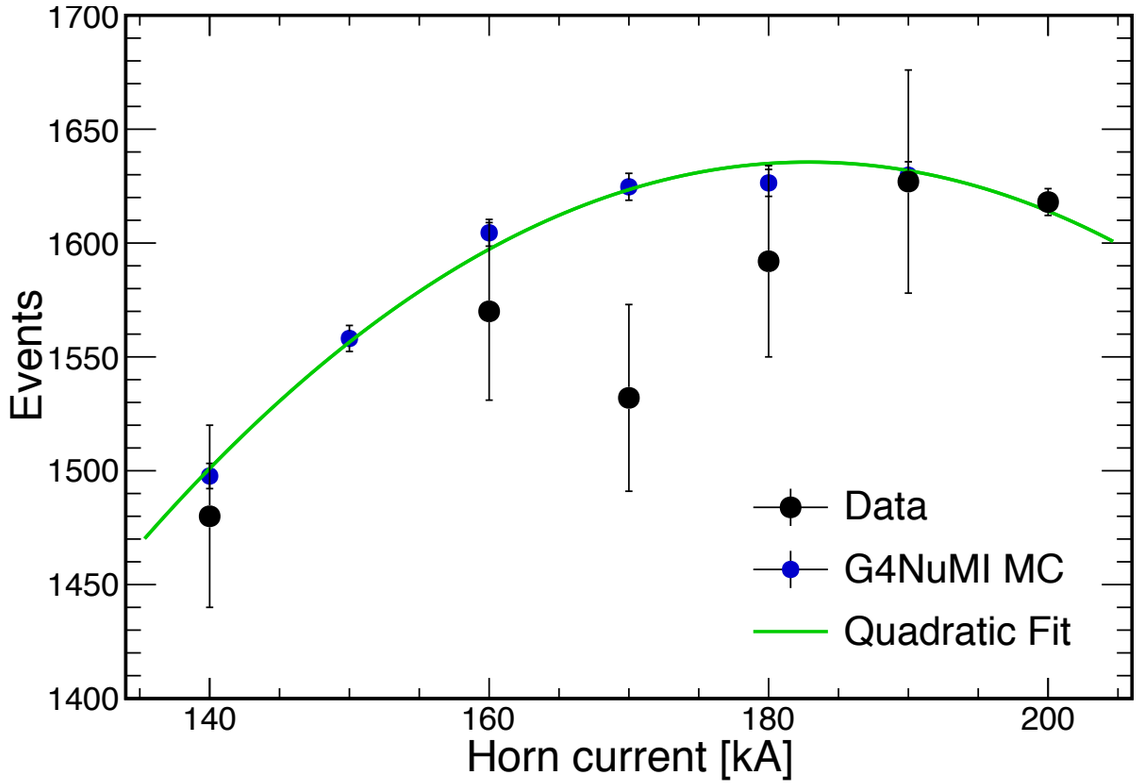
The plots in this slide show the FR predicted number of events (red and blue). These points have been fitted using a parabolic function: y = a + b*x + c*x*x.
The data points are shown in black.

Then a chi-squared test has been performed to see how much the data follow the y behavior (see next slide).

FLUGG



G4NuMI



Fit data-MC — Function

Given a, b and c from the FR fit, the chi-squared on the data points has been evaluated as:

$$\chi^2 = \sum_{i=1}^{M} \left(\frac{z_i - y_i(x_i, a, b, c)}{\sigma_i} \right)^2$$

M: number of points
$\mathbf{z_i}$: data point
$\mathbf{y_i}$: fitted function evaluated at x_i
$\mathbf{x_i}$: horn current
$\boldsymbol{\sigma_i}$: uncertainty on the data point

The results are (degree of freedom = 5):

FLUGG

$$\chi^2_F = 9.8$$

$$P(\chi^2 > \chi^2_F) = 8.1\%$$

G4NuMI

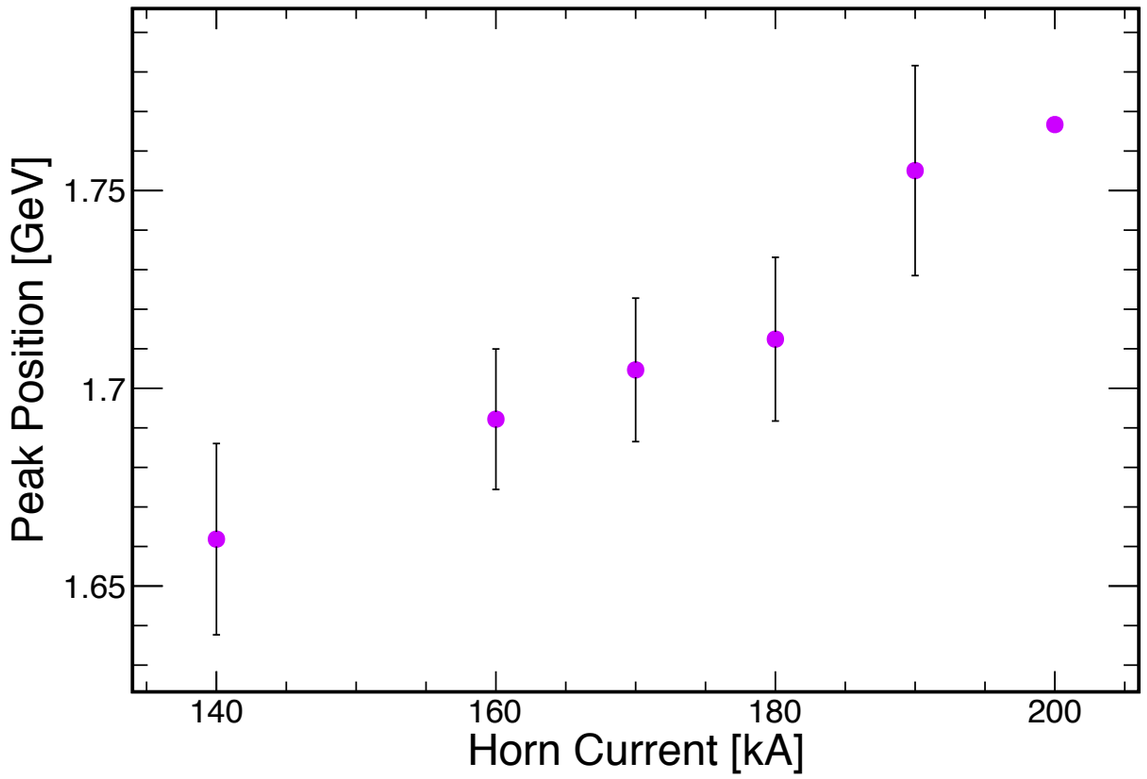
$$\chi^2_G = 6.8$$

$$P(\chi^2 > \chi^2_F) = 23.6\%$$

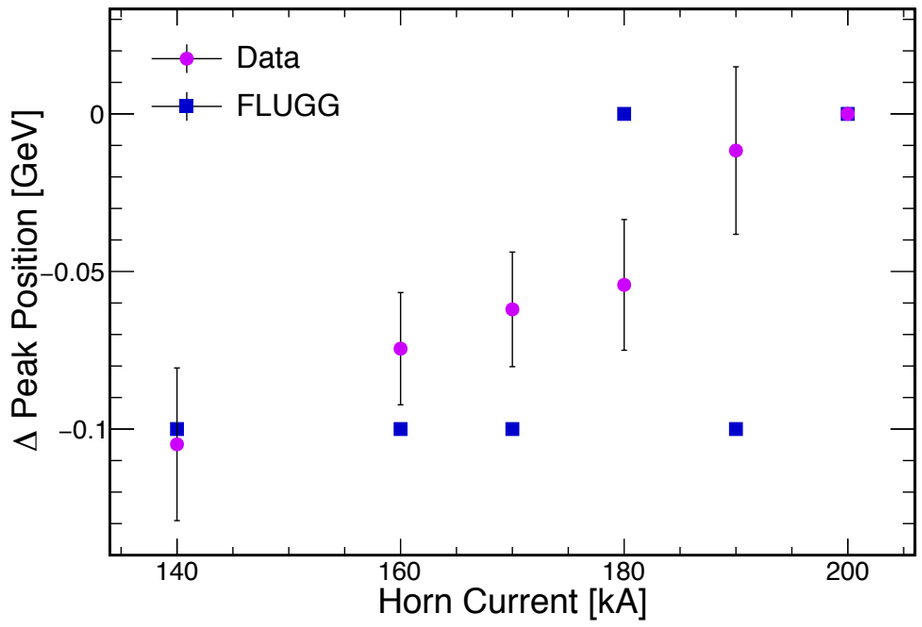
Peak Position

Peak Position VS Horn Current

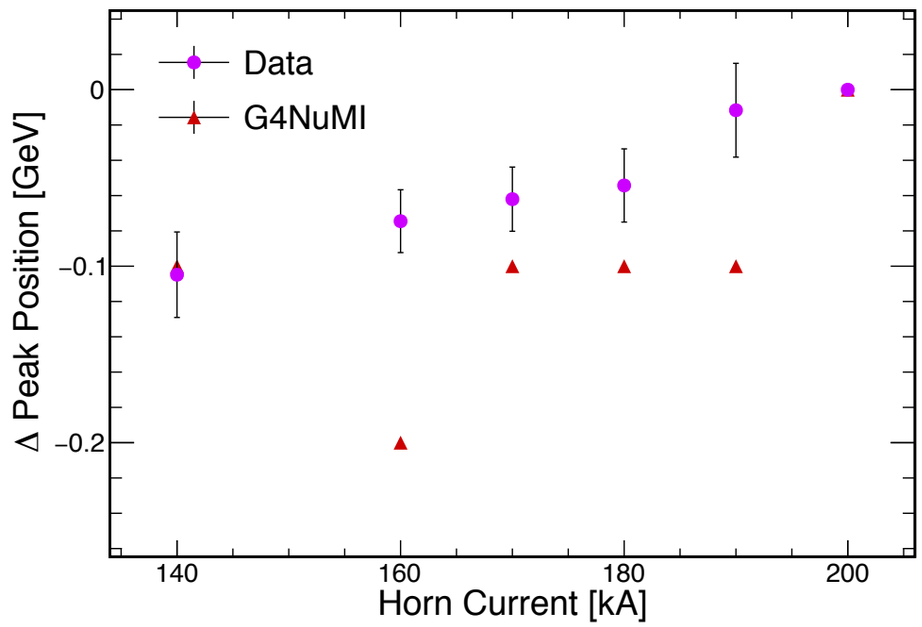
To look at how the peak position changes with the horn current, the reconstructed energy distributions have been fitted with a truncated gaussian in the proximity of the peak.



(Peak position @ i kA) - (Peak position @ 200 kA)



FLUGG



G4NuMI

Events and Peak Position

Events VS horn current

HC [kA]	Selected Events / 5.98e17 POT	(evts @ i) - (evts @ 200) percent
200	1618.0 ± 2.4	0
190	1627 ± 49	0.6 ± 3.0
180	1592 ± 42	-1.6 ± 2.6
170	1532 ± 41	-5.3 ± 2.5
160	1570 ± 38	-2.8 ± 2.4
140	1480 ± 40	-8.5 ± 2.5

Peak position VS horn current

HC [kA]	(Peak pos. @ i) - (Peak pos. @ 200) percent
200	0
190	-1.8 ± 1.3
180	-2.3 ± 1.2
170	-3.4 ± 1.1
160	-4.5 ± 0.9
140	-4.9 ± 1.2

Conclusions

- We wanted to confirm the MC prediction that the neutrino yield for NOvA is almost constant down to 160 kA with the special runs;
- Runs performed in June;
- Horn current set to: 190, 180, 170, 160, 140 kA;
- Data show that at 160 kA NOvA looses (2.8 ± 2.4)% of ν_μ CC events.
- The energy peak of ν_μ CC events shifts toward low energies, at 160 is (4.5 ± 0.9)% lower than at 200 kA.

Looking at the data, we notice some discrepancy with the MC:

- both simulations predict more events at any horn current value;
- it doesn't seem to be related to the physics lists since both FLUGG and G4NuMI show the same behavior;
- to understand if it is only an off-axis problem it would be useful to look at on-axis data.

<u>Is there some MINOS people working on that?</u>

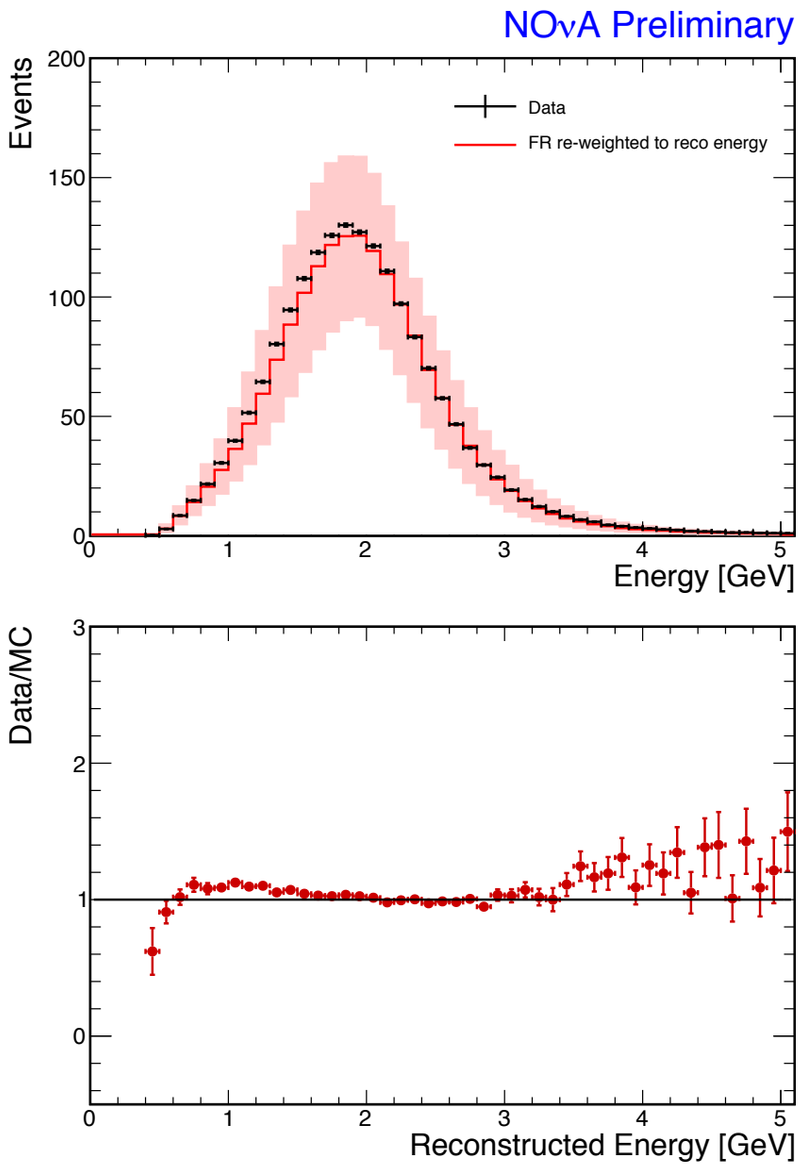
Back-up

Data & FluxReader energy distribution

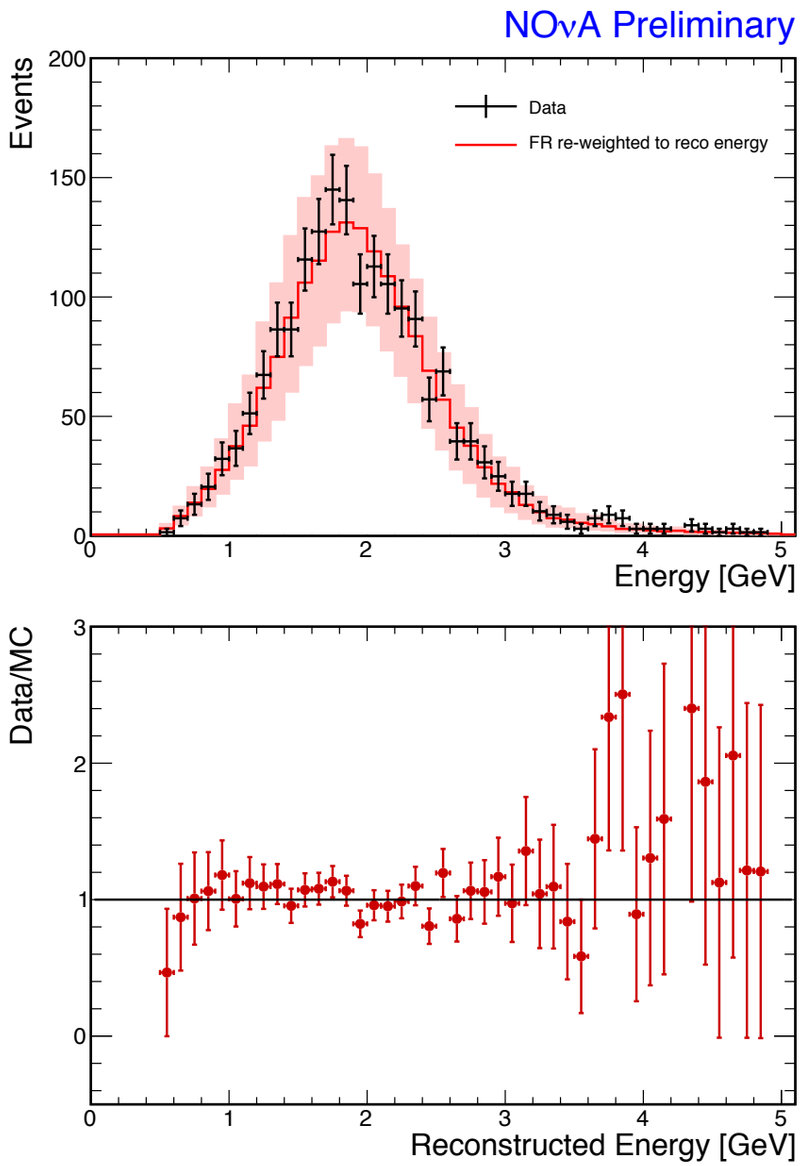
Data have been processed using the CAFAna package (S15-05-22).

For the event selection, Louise note has been taken as a reference (doc-db 13212).

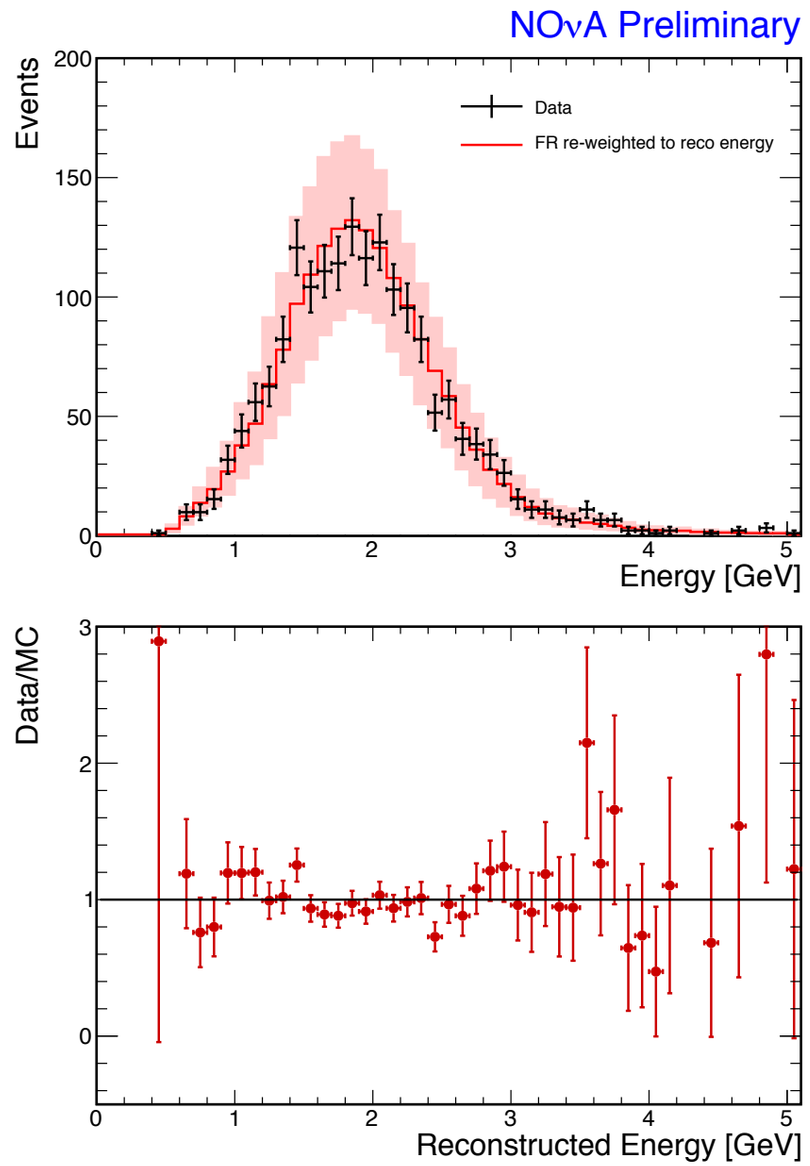
200 kA



190 kA



180 kA



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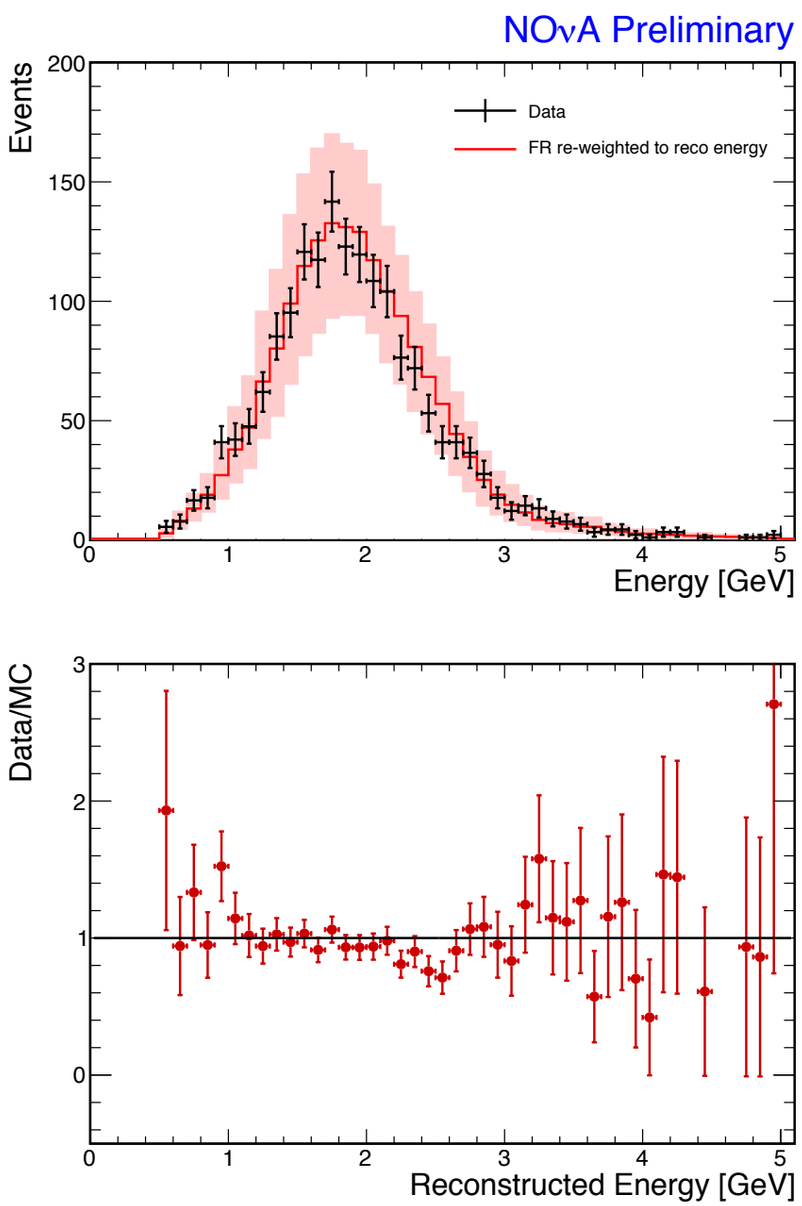
Data & FluxReader energy distribution

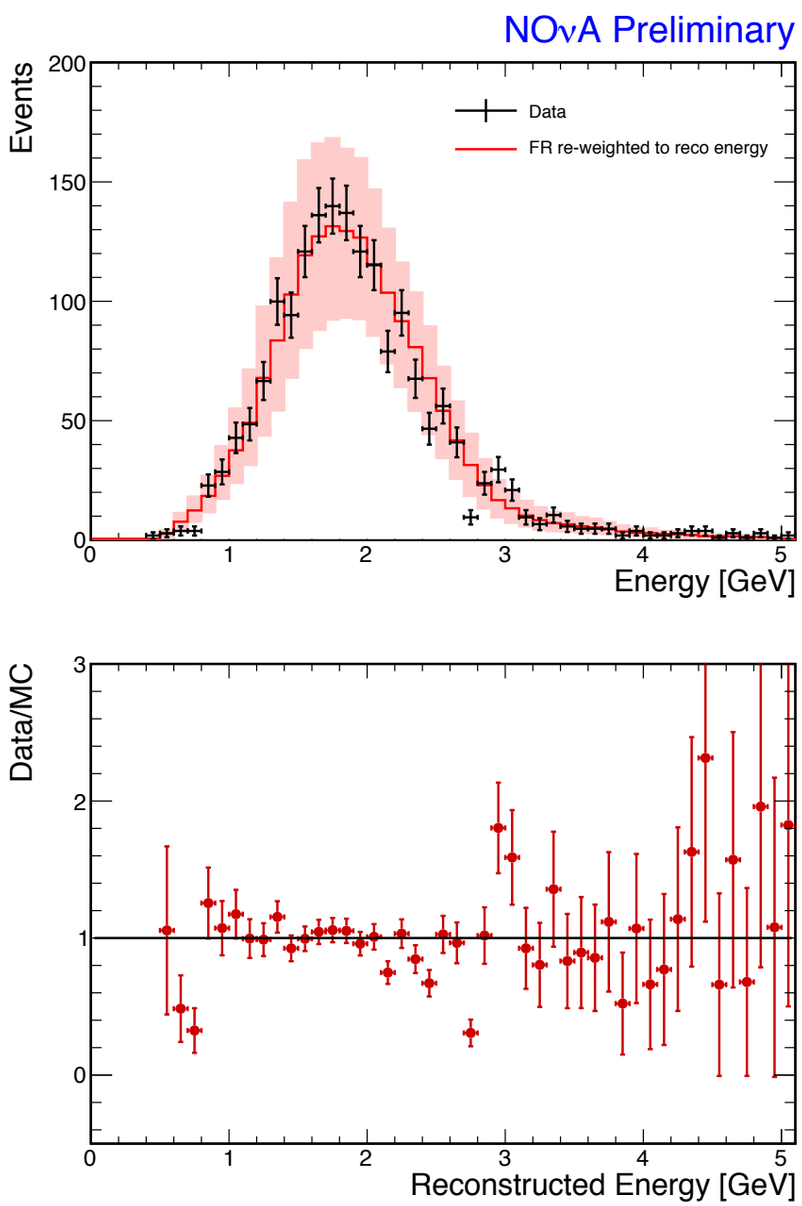
Data have been processed using the CAFAna package (S15-05-22).

For the event selection, Louise note has been taken as a reference (doc-db 13212).

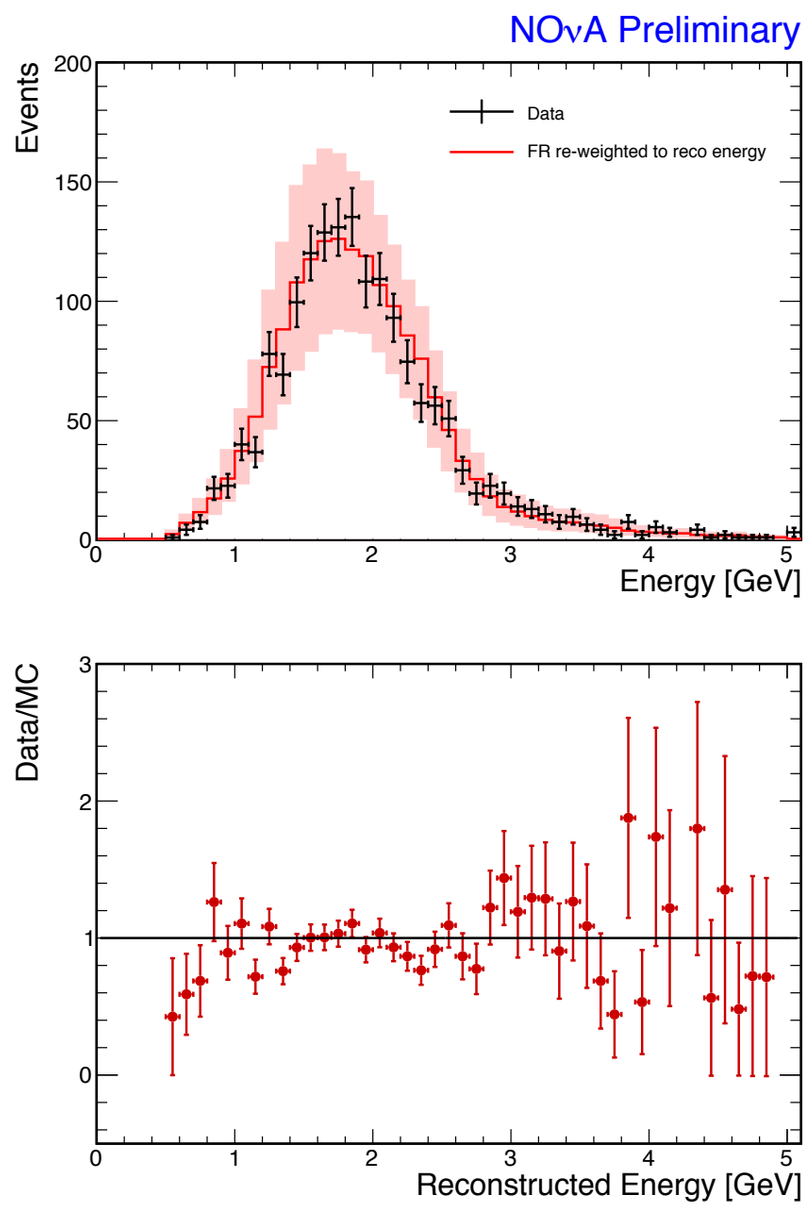
170 kA



160 kA



140 kA



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